

## Chapter 5 Microbial quality of drinking water



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### 5.1 Introduction

This chapter discusses the microbial characteristics of water quality. It describes the microorganisms found in drinking water that can be harmful to health, gives a historical overview of the control of waterborne infection and discusses the risk of disease from waterborne pathogens. It also discusses the ‘nuisance organisms’ that may affect the taste, odour or appearance of water but do not cause disease. Advice on when and how to measure the characteristics and how to interpret the results is provided in Part III.

### 5.2 Microorganisms in drinking water

The microbial guidelines seek to ensure that drinking water is free of microorganisms that can cause disease. The provision of such a supply is of paramount importance to the health of a community.

The most common and widespread health risk associated with drinking water is contamination, either directly or indirectly, by human or animal excreta and the microorganisms contained in faeces. If the contamination is recent, and those contributing to the contamination include carriers of communicable enteric diseases (diseases of the gut), some of the microorganisms that cause these diseases may be present in the water. Drinking such contaminated water or using it in food preparation may cause new cases of infection. Those at greatest risk of infection are infants and young children, people whose immune system is suppressed, the sick, and the elderly.

Pathogenic (disease-causing) organisms of concern include bacteria, viruses and protozoa; the diseases they cause vary in severity from mild gastroenteritis to severe and sometimes fatal diarrhoea, dysentery, hepatitis, cholera or typhoid fever.

The classic waterborne diseases are caused by organisms originating in the gut of humans or other animals. However, many organisms of environmental origin that are not normally associated with the gastrointestinal system are found in water, and some of these organisms may, under certain circumstances, cause disease in humans. Such organisms include the protozoan *Naegleria fowleri*, a number of bacteria, including *Pseudomonas*, *Klebsiella* and *Legionella* spp, and some species of environmental mycobacteria.

Infection is the main, but not the only, problem associated with microorganisms in drinking water. For instance, certain algae and bacteria can produce toxins that affect humans; the toxins may remain in the water even when the organisms responsible have been removed. Other ‘nuisance organisms’ can cause problems of taste, odour or colour, or promote deposition and corrosion.

The supply of safe drinking water involves the use of multiple barriers to prevent the entry and transmission of pathogens. The effectiveness of these barriers should be monitored by a program based on operational characteristics and testing for microbial indicators (see Sections 3.4 and 3.5).

This chapter presents a brief historical overview of waterborne infection, demonstrating the dramatic effectiveness of simple control measures and the use of indicator organisms to detect faecal pollution. It then discusses the characteristics and behaviour of the various groups of microorganisms and factors influencing the risk of disease. The chapter ends with a summary of nuisance organisms.

### 5.3 Controlling waterborne infection: a historical overview

The value of pure water supplies has been recognised, at least in some quarters, for millennia. Hippocrates described an association between water supplies and disease<sup>1</sup> and Roman engineers went to great lengths to provide water suitable in both quantity and quality for major cities.

Urbanisation and industrialisation increased the pressure on water supplies and systems of waste disposal, and by the middle of the 19th century, Britain was affected by major epidemics of cholera and endemic typhoid. John Snow and William Budd provided incontrovertible evidence of the role of water in transmission of these two diseases. Snow's case rested very simply on a comparison of cholera incidence among the customers of three London water companies (Snow 1855): one supplied filtered water; the second moved the source of its supply to a cleaner area of the Thames; the third persisted in supplying polluted Thames water. Budd appreciated that the sewer was merely the continuation of the diseased gut (Budd 1856), and applied what are now classic epidemiological concepts to the investigation of water as a vehicle for spreading typhoid. As a result, filtration of river-derived water became a legal requirement in London in 1859, and the practice gradually spread through Europe. By 1917, Sir Alexander Houston could draw attention to the effectiveness of London's systems of water treatment and delivery in stopping the waterborne transmission of typhoid. He pointed out that in America an annual mortality rate from typhoid of 20 or more per 100 000 people was considered normal (e.g. the rate in Minneapolis was 58.7); however, in London the annual mortality from typhoid was 3.3 per 100 000 (Houston 1917).

Budd's relatively simple precautions against typhoid were remarkably successful (Budd 1856). A century later, Hornick's experiments on volunteers helped to explain this success by showing typhoid to be relatively difficult to catch (Hornick *et al* 1966): around  $10^7$  *Salmonella enterica* serovar Typhi caused disease in only 50 per cent of his volunteer subjects. Kehr and Butterfield (1943), however, showed that a small minority of the population (about 1.5 per cent) need to ingest only a single typhoid organism to contract typhoid; to protect such individuals, more elaborate precautions are needed.

When the need to protect drinking water from faecal material was first recognised, the techniques available for the isolation of organisms such as *Salmonella enterica* serovar Typhi and *Vibrio cholerae* were quite inadequate for practical purposes. Surrogates were needed, and the obvious candidates were the coliforms, common flora from the gut. Thus, the use of indicator organisms became established. A consensus rapidly developed about the use of coliform organisms, and the work of Alexander Houston (1917), Doris Bardsley (1934) and many others helped to establish the validity of *Escherichia coli* as an indicator of faecal contamination.

Kehr and Butterfield (1943) showed the coliform test to be a useful indicator of *S. enterica* serovar Typhi. The authors concluded that the presence of even moderate numbers of coliforms presented a high risk, citing an outbreak in Detroit, Michigan, where mean coliform counts in the water supply of only 3 and 10 colony forming units (CFU) in every 100 mL of water on two successive days were the indicator for an outbreak of waterborne typhoid. Kehr and Butterfield also noted the much greater risk of gastroenteritis associated with this low coliform count: for the eight cases of typhoid recorded in this outbreak, there were 45 000 cases of gastroenteritis.

Endemic and epidemic cholera and typhoid both still occur, transmitted through contaminated drinking water. For example, this has been demonstrated in recent years in Priština (Yugoslav Typhoid Commission 1964), South Africa (Küstner *et al* 1981) and Peru (Anderson 1991). In Australia, fortunately cholera and typhoid are rare.

1. *On Airs, Waters and Places*, available online at [classics.mit.edu/Hippocrates/airwatpl.8.8.html](http://classics.mit.edu/Hippocrates/airwatpl.8.8.html)

## 5.4 Waterborne pathogens

### 5.4.1 BACTERIAL PATHOGENS

#### *Excreted pathogens*

The human bacterial pathogens that can be transmitted by consuming contaminated drinking water, and that present a serious risk of disease, include *Salmonella* spp, *Shigella* spp, enterovirulent *E. coli*, *Vibrio cholera*, *Yersinia enterocolitica*, *Campylobacter jejuni* and *C. coli*.

After being excreted in faeces from the body of their host, bacterial pathogens gradually lose viability and the ability to cause infection. The rate of decay varies with different bacteria; it is usually exponential, and after a certain period a pathogen will become undetectable. The most common waterborne pathogens are those that are highly infectious or highly resistant to decay outside the body. Pathogens with a low persistence (i.e. those that do not survive long outside the host) must rapidly find a new host and are more likely to be spread by person-to-person contact or by poor personal or food hygiene than by drinking water.

If drinking water is faecally contaminated, bacterial pathogens are likely to be widely and rapidly dispersed. Outbreaks of waterborne disease are therefore frequently characterised by infection across a whole community.

#### *Pathogens growing in water supplies*

Various bacteria that occur naturally in the environment may cause disease opportunistically in humans. Those most at risk are people with impaired local or general defence mechanisms, such as the elderly, the very young, people with burns, people who have undergone recent surgery or who have suffered serious injury, and people with severely compromised immune systems. In such individuals, if water used for drinking or bathing contains large numbers of opportunistic pathogens it can occasionally produce infections of the skin, and of the mucous membranes of the eye, ear, nose and throat. Examples of such opportunistic agents are *Pseudomonas aeruginosa*, species of *Klebsiella* and *Aeromonas*, and certain slow-growing mycobacteria.

Legionellosis, commonly caused by the free-living bacterium *Legionella pneumophila*, is a serious illness resulting from inhalation of water in which the causative organisms have been able to multiply because of warm conditions and the presence of nutrients.

Part V contains fact sheets on the bacterial pathogens that may contaminate the water supply.

### 5.4.2 PROTOZOA

The great majority of protozoa in freshwater are natural aquatic organisms of no significance to health. They generally feed on other microorganisms such as bacteria, cyanobacteria or algae. The greatest diversity of protozoa is found in open surface waters, including water supply sources, but some species can colonise piped water supplies; the extent to which this occurs depends on bacterial activity in these supplies.

The protozoa that may occur in drinking water and cause adverse health effects fall into two functional groups:

- enteric protozoa that occur widely as parasites in the gut of humans and other mammals
- free-living organisms that are opportunistic pathogens in humans and are responsible for serious cerebral and eye diseases (there are very few such organisms).

Since pathogenic protozoa are of both enteric and environmental origin, and since different species vary in their responses to water treatment, control strategies need to be specifically tailored to the biology of individual species.

### *Enteric protozoa*

Enteric protozoa, like enteric bacteria and viruses, may be found in water following direct or indirect contamination with human or animal faeces. Transmission by drinking water is one of several mechanisms for completing the faecal-oral cycle for these organisms. Enteric protozoa occur in water as dormant infectious cysts; the cysts have natural mortality rates that are probably determined by temperature and incident ultraviolet light.

In principle, removal or disinfection at the water source should be sufficient to prevent contamination of drinking water by enteric protozoa, provided adequate measures are in place to prevent later recontamination. In practice, this may be difficult because protozoan cysts are generally more resistant to water disinfectants than most bacteria and viruses.

*Cryptosporidium* and *Giardia* species are likely to be the most important enteric protozoa in water in Australia, although infection by *Entamoeba histolytica* is also endemic in some communities. All these organisms cause moderate to severe enteritis in susceptible people; in Australia, they seem to be transmitted mostly by direct contact with a carrier. Outbreaks of *Cryptosporidium* in humans are associated with contamination from human or livestock (particularly cattle), and faulty or inadequate treatment. There is evidence that *Giardia* infections in Australia may result from contact with septic-tank waste or from recent faecal contamination of drinking water.

### *Free-living protozoa*

Two groups of free-living amoebae, *Naegleria* and *Acanthamoeba*, have been responsible for human infections in Australia. Infection is opportunistic, and generally results from contact during recreational bathing, or domestic uses of water other than drinking. Public water supplies can contaminate swimming pools. The occurrence of these organisms is unrelated to faecal contamination, and their ecology in aquatic environments is more complex than that of enteric protozoa.

Cerebral infection by *Naegleria fowleri* is strictly waterborne and, although rare, is usually fatal. Since these amoebae are able to colonise piped water supplies, disinfection at the water source may not adequately control them unless the disinfectant pervades the whole distribution system.

*Acanthamoeba* species cause both cerebral and corneal disease. An environmental source of infection has rarely been identified with certainty. Since *Acanthamoeba* species are among the most common protozoa in soil, as well as occurring in freshwater and seawater, the source of infection may often be soil or airborne dust.

Both *Acanthamoeba* and *Naegleria* species are known to support symbiotic growth of *Legionella* species within the cell, and the presence of these amoebae in cooling-tower water can indicate conditions that favour *Legionella*.

Part V contains fact sheets on the protozoan pathogens that may contaminate the water supply.

### 5.4.3 VIRUSES

Viruses are among the smallest of all infectious agents. In essence they are molecules of nucleic acid that can enter cells and replicate in them. The virus particle consists of a genome, either ribonucleic acid (RNA) or deoxyribonucleic acid (DNA), surrounded by a protective protein shell, the capsid. Frequently this shell is itself enclosed within an envelope that contains both protein and lipid. Viruses replicate only inside specific host cells, and they are absolutely dependent on the host cell's synthetic and energy-yielding apparatus for producing new viral particles.

The viruses of most significance for drinking water are those that multiply in the human intestine and are excreted in large numbers in the faeces of infected individuals. Although they cannot multiply outside the tissues of infected hosts, some enteric viruses can survive in the environment and remain infective for long periods. Human enteric viruses occur in water largely as a result of contamination with sewage and human excreta. The numbers of viruses present and their species distribution will reflect the extent to which they are being carried by the population; however, the use of different analytical methods can also lead to wide variations in calculations of the numbers of viruses found in sewage. Sewage treatment may reduce numbers by a factor of 10 to 10 000, depending upon the nature and degree of treatment; however, even tertiary treatment of sewage will not eliminate all viruses. As sewage mixes with receiving water, viruses are carried downstream; the length of time they remain detectable depends on temperature, their degree of adsorption to particulate matter, penetration of sunlight into the water and other factors. Consequently, enteric viruses can be found at the intakes to water treatment plants if the water is polluted by sewage. However, proper treatment and disinfection should produce drinking water that is essentially virus free.

Recent methodological advances have revolutionised the diagnosis of viral diarrhoeal diseases, and waterborne outbreaks due to viruses have now been identified in both developed and developing countries all over the world, with many different strains of viruses isolated from raw and treated drinking water. Isolation of viruses from water indicates that a hazard exists, but it does not prove beyond doubt that water is a vehicle for transmission of disease.

Epidemiological proof of waterborne transmission of viral diseases is very difficult to establish, for a variety of reasons. Symptoms may not resemble those of typical waterborne diseases, and many of those infected will show no symptoms. Some infections, for example the hepatitis A virus, are difficult to trace to a source because of long incubation periods. Water is often only one of various routes of transmission, it is not always the major route, and adequately sensitive methods for detecting the infectious agent in water are often not available.

Part V contains fact sheets on the viral pathogens that may contaminate the water supply.

### 5.4.4 HELMINTHS

The major helminth (worm) parasites of humans listed by the World Health Organization as being transmitted by water do not occur in Australia, apart from their rare incidence in recent immigrants or Australians returning from areas where the organisms are endemic. The eggs of enteric nematodes such as *Trichurus* may enter water, but waterborne transmission is generally regarded as unimportant. Nematodes seen as adult worms or larvae in microscopic examination of material from water supplies are likely to belong to free-living groups such as *Turbatrix* or *Rhabditis*, which, like free-living protozoa, colonise systems that support other microorganisms.

Infective enteric helminths should not be present in drinking water; however, it is impracticable to set guidelines due to the low prevalence of these agents in Australia.

### 5.4.5 CYANOBACTERIA

Cyanobacteria are true bacteria, although they are often called 'blue-green algae' because they resemble green algae in morphology, habitat and photosynthetic ability. They occur as single cells, filaments or colonies, and their buoyancy enables them to migrate towards the surface of water in response to light. Cyanobacteria inhabit all natural waters, and become a problem only when present in excessive numbers (blooms). This is more likely to occur when temperatures are high, with long sunny days, high levels of plant nutrients in the water, low stream flows, and calm conditions that permit the cells to migrate to the surface. These conditions occur sporadically in late spring through to autumn in many parts of Australia. In addition, eutrophication (nutrient enrichment) associated with increased agriculture and urbanisation has increased the occurrence of cyanobacterial blooms.

They are of concern in drinking water primarily because of the intracellular toxins they produce, which are of three main types:

- hepatotoxins, which damage liver cells
- neurotoxins, which damage nerve cells
- cylindrospermopsin which can damage the liver, kidney, gastrointestinal tract and blood vessels.

No human deaths have been recorded from ingesting the toxins of cyanobacteria but gastroenteritis may result from drinking water containing toxic species and extended exposure may lead to more serious impacts. Deaths have been attributed to the presence of microcystin in water used for renal dialysis in Caruara, Brazil (Jochimsen *et al* 1998).

Direct contact with toxic or non-toxic species of cyanobacteria may cause skin rashes or eye irritation due to adverse reactions to components in the cell walls of the organisms. This could occur through showering or bathing in water containing blooms or scums.

Part V contains fact sheets on cyanobacteria.

## 5.5 Risk of disease from waterborne pathogens

Drinking water is only one of several means by which many infectious agents can be transmitted. It can, however, be of considerable importance, and many pathogens that are excreted in faeces have caused epidemics through contaminated water. The significance of a particular organism in water can vary considerably; for example, a potentially pathogenic organism will not always cause symptomatic disease in a particular individual. The chances of waterborne infections occurring in a community depend on:

- the concentration of pathogenic organisms in the water
- the virulence of the strain
- the per capita intake of contaminated water
- the infectious dose of the particular pathogen
- the susceptibility of individuals
- the incidence of the infection in the community (which will determine the numbers of pathogens being excreted).

The occurrence of disease is also related to the relative level of immunity in the community. If, for example, the water supply has been repeatedly contaminated, the community may have become immune to some waterborne pathogens. Such a situation can be seen in some developing countries where the prevalence of pathogens is high and the standard of tap water is less than optimal. Visitors who drink the water frequently become ill, while the local community, especially adults, appear to suffer minimal morbidity. The immunity of the local population may, however, be acquired at the expense of the health of more susceptible individuals in that community, including children, the aged and people already in poor health.

Thus, a community consuming water with indicators of faecal pollution may show no discernible disease. Such a situation, however, is unstable. Apart from the risk to visitors, faecal pathogens affecting the locals may be introduced from, for instance, an immigrant or a seasonal outbreak of a disease such as cryptosporidiosis resulting from cattle in the catchment.

When illness occurs in a community, the route of infection needs to be confirmed by epidemiological investigation, even when the disease-causing organism is found in a suspect water supply.

## 5.6 Nuisance organisms

Nuisance organisms comprise a morphologically and physiologically diverse collection of organisms. They include:

- procaryotic bacteria such as planktonic and benthic cyanobacteria (blue-green algae)
- iron, manganese and sulfur bacteria
- actinomycetes and fungi
- eucaryotic organisms such as algae, crustacea and protozoa.

Problems occur when the conditions in source waters, reservoirs or distribution systems support the growth of a particular nuisance organism or group of nuisance organisms. Excessive quantities of organic matter, for instance, will support the growth of bacteria and fungi, and these will maintain populations of protozoa and crustacea. Many invertebrate animals can feed on bacteria, fungi and protozoa.

In addition, a particular nuisance organism may show morphological characteristics or produce some extracellular product that gives the organism a competitive advantage over other aquatic inhabitants. This may include a 'holdfast' (i.e. a mechanism for anchoring the organism) or sheath (in the case of some iron bacteria) or the ability to produce antibiotic substances (as in some fungal species).

Raw water does not usually contain sufficient numbers of nuisance organisms to create problems; however, the water treatment process may assist their growth. Nuisance organisms concentrate on the surface of filters and inside the filter bed, and on mains and water reservoir surfaces, where they lyse and release cellular compounds responsible for colour, turbidity, taste and odour. Activated carbon filters will, after a period, contain high amounts of organic matter; this may affect taste and odour, and increase turbidity, providing an excellent substrate for bacteria. Poorly operated filter systems, including activated carbon-based domestic filter systems, can be the source of tastes and odours.

It is not practicable to specify a quantitative limit for nuisance microorganisms.

### 5.6.1 ORGANISMS CAUSING TASTE AND ODOUR PROBLEMS

Objectionable tastes and odours can result from compounds produced by certain types of algae, cyanobacteria (blue-green algae), bacteria and sometimes protozoa. Actinomycetes and cyanobacteria, for instance, produce geosmin and methylisoborneol (MIB), which have an earthy taint, and a taste and odour threshold of approximately 0.00001 mg/L (10 ng/L).

Several groups of protozoa produce odorous compounds in culture. Certain species of the amoeba genera *Vannella*, *Saccamoeba* and *Ripidomyxa* that carry rather dense bacterial symbionts also produce either geosmin or MIB. Most previously described sources of these compounds have been cyanobacteria or actinomycetes, so it seems likely that the symbionts are the immediate source. While the mechanism of symbiont contribution to odours in waters is unknown, they should be considered as the likely source of a problem if no other biological source of these strongly smelling compounds can be identified.

Free-swimming ciliates, such as *Climacostomum* and certain *Stentor* species that bear the algal symbionts zoochlorelle, can contribute to odours in water if they reach high densities, although such incidents are not often reported.

Consumers often detect taste and odour problems before analytical methods have detected the compounds responsible. It is therefore advisable to use trained panels to detect taste and odour, and undertake remedial measures before a problem becomes significant. Section 3.5.2 and Fact Sheet on *Taste and odour* in Part V discuss such panels.

Another method to pre-empt taste and odour problems is to use microscopy to examine regularly the type and number of organisms present in the water. When a group of organisms known to cause taste or odour problems is dominant, measures should be taken to overcome the problem.

### 5.6.2 ORGANISMS CAUSING COLOUR PROBLEMS

Excessive growths of some algae, cyanobacteria and other bacteria can produce undesirable 'blooms' in source waters, and this may affect colour in the distribution system.

Blooms of algae and cyanobacteria may be controlled by judicious application of copper sulfate or other algicides to the source water, provided that the cyanobacterial genus is not toxic.

When pigmented organisms such as cyanobacteria and algae are crushed on filters, colour problems can result. This type of problem can be exacerbated by the passage of microalgae through the filters causing an increase in turbidity.

### 5.6.3 DEPOSITS DUE TO IRON AND MANGANESE BACTERIA

Nuisance iron oxidising organisms may cause problems in groundwater sources by encrusting bore screens, causing loss of yield and impairing the aesthetic quality of the supply. The presence of these organisms may also indicate organic pollution of the aquifer.

Manganese-oxidising organisms (bacteria, fungi and, very rarely, protozoa) may be responsible for deposits in aquifers, wells and water conduits. The deposits can reduce yield, clog slots in the bore pipes, slow the flow in pipes by increasing turbulence, damage equipment for measuring water flows, and produce black water that stains laundry and disrupts food-handling establishments. Bacteria can attach to the deposits; if disturbed, these will increase the heterotrophic colony count of the water. These problems will generally not occur if the concentration of manganese is below 0.1 mg/L. (See Fact Sheet on *Manganese*)

In water containing ferrous or manganous salts, iron or manganese bacteria can oxidise these compounds to form rust-coloured or black deposits in tanks and on the walls of pipes in slow-flowing parts of the distribution system. Changes in water flow can then release the deposits into the supply system, staining laundry and plumbing fittings, and adversely affecting the appearance of drinking water. The slurry may also contain organic deposits that can break down to cause odour problems. (See Fact Sheets on *Colour, Iron, and Manganese*.)

Although these nuisance organisms can impair water quality, it is not practicable to monitor for them routinely because of their diverse nature and unpredictable occurrence. Consumer complaints, together with local knowledge of the water supply system and water sources, should be a trigger for action.

#### 5.6.4 CORROSION PROBLEMS DUE TO IRON AND SULFUR BACTERIA

Iron and sulfur bacteria contribute to the corrosion of iron and steel well pipes and drinking-water mains, with corrosion starting from either inside or outside. Microorganisms may cause corrosion by:

- depleting dissolved oxygen
- preventing corrosive metabolites
- producing sulfuric acid from sulfides or elemental sulfur
- participating in the cathodic process.

The presence of these organisms in water may indicate a potential for corrosion of cast iron mains and storage tanks. It can also indicate biodeterioration of certain construction materials, including nonmetallic materials such as plastics, rubber jointing compounds and pipe lining materials, which provide organic nutrients and thus encourage the growth of microorganisms such as *Pseudomonas aeruginosa*.

#### 5.6.5 PROBLEMS CAUSED BY LARGE NUMBERS OF MICROORGANISMS

Large numbers of aerobic heterotrophic bacteria in treated water can interfere with the interpretation of tests for the coliform group by masking their presence, thus yielding false-negative results. Strains of *Aeromonas* species that produce acid and gas with coliform media, even at 44°C, present a particular problem.

Most of these organisms can be controlled relatively easily by water treatment processes, including disinfection. Nutrient-rich raw water should be avoided if water treatment cannot be applied.

#### 5.6.6 NUISANCE INVERTEBRATES

Invertebrate animals often infest shallow open wells, warm shallow storage tanks and small supplies, but problems are uncommon in large public supplies. These invertebrates derive their food from bacteria, algae and protozoa that are present in the water or on slimes. They include freshwater sponges of the phylum Porifera (*Spongilla* spp and *Ephydatia* spp), a coelenterate (*Cordylophora* spp), bryozoans (*Plumatella* spp and *Fredericella* spp) and molluscan bivalves and snails (e.g. *Corbiculina* spp).

For control purposes, the types of animal can be divided into two groups:

- free-swimming organisms, such as the crustacea *Gammarus pulex* (freshwater shrimp), *Crangonyx pseudogracilis*, Cyclops species and *Chydorus sphaericus*
- animals that either move along surfaces or are anchored to them, such as *Asellus aquaticus* (water louse), snails, *Dreissena polymorpha* (the zebra mussel) and other bivalve molluscs, the bryozoan *Plumatella* species, or animals that inhabit slimes, such as *Nais* species, nematodes, and larvae of chironomids.

In warm weather, slow sand filters can sometimes discharge larvae of midges and mosquitoes into the water. This occurs if the top layer of the bed collapses, causing unfiltered water to be drawn down.

Nuisance invertebrates are more likely to penetrate water filtration plant and mains when low-quality raw waters and high-rate filtration processes are used. Prechlorination destroys the invertebrates and thereby assists their removal by filtration; however, the use of high concentrations of chlorine may produce high levels of chlorination byproducts. Infestation can usually be prevented by maintaining chlorine residuals in the distribution system, producing high-quality water and cleaning water mains regularly by flushing or swabbing.

## 5.7 References

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